POLLUTION PREVENTION FOR THE WOOD FINISHING INDUSTRY

DEVELOPED BY:

U.S. EPA/SEDESOL
POLLUTION PREVENTION
WORKGROUP

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LIMITATIONS OF THIS MANUAL

This manual provides an overview of the pollution prevention and recycling alternatives that are available in the wood finishing industry. This report is intended only to assist the user in his or her preliminary research and development of pollution prevention options. Each company is responsible for identifying, evaluating, and implementing pollution prevention practices that are appropriate to its specific situation. By compiling and distributing this manual, EPA and SEDESOL are not recommending the use of any particular processes, raw materials, products, or techniques in any particular industrial setting. Compliance with U.S. and Mexican environmental laws, occupational health and safety laws, and all applicable federal, state, and local laws and regulations is the responsibility of each individual business. It is not the focus of this document.

The information in this manual is intended to be a relatively comprehensive overview of the documented information on pollution prevention and recycling practices for the wood finishing industry. However, the collection, organization, and dissemination of pollution prevention information is a relatively new undertaking, as well as an ongoing and evolutionary process. In addition, there are limits to any manual, including this one. Therefore, this summary may not contain every relevant piece of information on pollution prevention and recycling for wood finishing companies. EPA encourages all users who discover, in the literature or in the field, pollution prevention options that are not cited in this report to share this information with EPA. Please submit any corrections, updates, or comments on this report to the following:

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This manual is an assimilation of existing research and case studies of waste minimization and pollution prevention principles. Because of the voluminous amount of such information, referencing sources in the text as and when they are used would make the manual cumbersome to the reader. Therefore, the authors of this manual wish to acknowledge the authors of all of the articles referenced throughout the text and listed in the bibliography section.

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INTRODUCTION

The production of economically competitive products is the driving force behind any successful business. Manufacturing frequently requires the use of various chemicals. The purchase and storage of these chemicals, their use in the process, and the ultimate disposal of the waste generated by the manufacturing process can present many problems. These problems include financial concerns, environmental management, and worker health and safety.

Pollution prevention (also referred to as waste minimization or source reduction) is the use of materials, processes, or practices that reduce or eliminate the generation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous and nonhazardous materials, energy, water, and other resources, in addition to practices that protect natural resources through conservation or more efficient use.

Because of the enormous potential for pollution prevention along the U.S.-Mexico border, the U.S. Environmental Protection Agency (EPA) and Secretaria de Desarrollo Social (SEDESOL) established the Pollution Prevention Workgroup in February 1992. EPA and SEDESOL also began promoting and coordinating the reduction of pollution through a broad range of approaches: technical assistance, training, public and private sector programs in pollution prevention awareness, assessment of pollution prevention opportunities, policy development and institutional support, and technology development and investment activities.

The purpose of this manual is to provide pollution prevention information for the wood finishing industry. This manual builds on the effort of the first manual —"Waste Minimization for the Metal Finishing Industry." That manual was the first in this series of bilingual pollution prevention manuals prepared jointly by EPA and SEDESOL. Future manuals will include other industries that are typical in the border area. The manual contains the following sections:

Section I — Goals and Benefits of Pollution Prevention

In this general introduction, the term "pollution prevention" is clarified. This section also includes an overview of the benefits of applying pollution prevention techniques.

Section II — Pollution Prevention in the Wood Finishing Industry

This technical section describes various processes associated with the wood finishing industry and pollution prevention options for that industry.

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Section III Case Studies

This section includes specific examples of companies that have used pollution prevention techniques. These case studies describe the benefits, particularly cost savings, that these companies have achieved.

Appendix Additional Information

This section lists additional technical documents pertaining to pollution prevention opportunities for the wood finishing industry, and other information. These documents are currently available only in English.

Attachment A Information on Accessing Pollution Prevention Information Clearinghouses

This section describes how to access the International Cleaner Production Information Clearinghouse (ICPIC) database, which is an international clearinghouse for pollution prevention information. Information is also included on how to access the Pollution Prevention Information Exchange System (PIES).

Attachment B Survey

PLEASE COMPLETE THE SURVEY INCLUDED IN THIS SECTION. Your response provides valuable information for evaluating the usefulness of this manual. Additionally, when your survey is returned, your name will be placed on a mailing list for updates to the manual and other documents as they become available.

Section I

Goals and Benefits of Pollution Prevention

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GOALS AND BENEFITS OF POLLUTION PREVENTION

POLLUTION PREVENTION GOALS

The goal of a pollution prevention program is to improve the quality of the environment through eliminating, preventing, and/or reducing all waste generation. Pollution prevention includes any action by a company to reduce the amount of waste generated by a manufacturing process prior to off-site recycling, treatment, or disposal of the waste. To effectively accomplish this, the program must include an ongoing, comprehensive assessment of the operations at a facility.

BENEFITS OF A POLLUTION PREVENTION PROGRAM

Businesses and governments have strong incentives to reduce the toxicity and volume of the waste that they generate. ***As pollution prevention activities lower operating costs, production costs will decrease. Therefore, companies with an effective, ongoing pollution prevention plan will have a significant competitive edge.***

As discussed in detail below, a pollution prevention program can achieve the following benefits:

- Protect human health and environmental quality.
- Reduce operating costs.
- Improve employee morale and participation.
- Enhance the company's image in the community.
- Assist in compliance with environmental laws.

Protect Human Health and Environmental Quality

Reducing the waste released to air, land, and water will enhance the environment and protect human health. Typical harmful pollutants that can be reduced significantly by pollution prevention techniques include the following:

- Air emissions, including solvent fumes, fine particulates, and carbon monoxide

- Land disposal, including ash from incineration, waste solvents, and debris

- Water disposal, including wastewater contaminated with solvents and other toxic materials

Volatile organic compounds (VOC) typically comprise a significant amount of the solvents used in wood finishing. VOCs are central nervous system depressants. High exposures (hundreds to thousands parts per million in the air) may result in giddiness, confusion, unconsciousness, paralysis, and death from respiratory or cardiovascular arrest. Long-term exposure may result in behavioral effects. Some VOCs are suspected carcinogens.

The health and safety of employees can be affected by poor ventilation, mishandling of chemicals, and a lack of proper safety equipment. An informative employee training program is an important way to reduce accidents. Reducing the amount of chemical materials and wastes at a facility is also beneficial, because it reduces the amount of space required for storage and the potential for accidental spills. Furthermore, hazardous waste transportation requirements may be reduced if the volume of pollution is minimized.

Reduce Operating Costs

An effective pollution prevention program can yield cost savings that will more than offset program development and implementation costs. Cost reductions may be immediate savings that appear directly on the balance sheet or anticipated savings based on avoiding potential future costs. Cost savings are particularly noticeable when the costs resulting from the treatment, storage, or disposal of wastes are allocated to the production unit, product, or service that produces the waste.

Materials costs, or the costs of purchasing materials, can be reduced by adopting production and packaging procedures that consume fewer resources. This approach uses resources more efficiently and reduces the quantity and toxicity of waste generated. As wastes are reduced, the percentage of raw materials converted to finished products increases. This results in a proportional decrease in materials costs.

Waste management and disposal costs may be reduced when less waste is produced. Required procedures for proper handling of the waste at the facility —in addition to specific treatment, disposal, and transportation methods - are typically labor—intensive and very costly. These requirements and their associated costs are expected to increase.

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Production costs can be reduced through a pollution prevention assessment. When people examine production processes from a fresh perspective, they find opportunities for increasing efficiency that might not, otherwise, have been noticed. Production scheduling, material handling, inventory control, and equipment maintenance are all areas in which facilities can work to reduce the production of waste of all types, thereby controlling the costs of production.

Energy costs will decrease as the facility implements pollution prevention measures in various production lines. In addition, by thoroughly assessing how operations interact, companies can reduce the energy used to operate the overall facility.

Improve Employee Morale and Participation

Employees are likely to feel better about their company when they believe that management is committed to providing a safe work environment and is acting as a responsible member of the community. By participating in pollution prevention activities, employees have an opportunity to be part of a "team," and interact positively with coworkers and management. Helping to implement and maintain a pollution prevention program will normally increase each employee's sense of commitment to company goals. This positive atmosphere helps to retain a competitive work force and to attract high-quality new employees.

Enhance the Company's Image in the Community

The quality of the environment has become an issue of critical importance to society. Your company’s policy and practices for controlling waste increasingly influence the attitudes of the local community at large.

Community attitudes are more positive toward companies that operate and publicize a thorough pollution prevention program. If a company creates environmentally compatible products and avoids excessive use of material and energy resources, the company's image will be enhanced both in the community and with potential customers and consumers.

Assist In Compliance With Environmental Laws

Mexico's environmental laws include administrative penalties that entitle government inspectors to require temporary or permanent closure of businesses that are not in environmental compliance. A pollution prevention plan that includes standard operating procedures that comply with environmental laws and regulations is very helpful. By following the plan, a company increases its chances of avoiding violations and associated penalties.

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WHAT IS POLLUTION PREVENTION?

Pollution prevention (also known as source reduction and waste minimization) is any action that reduces the production of wastes (at their source) that may be released to the air, land, or water. ***Two general methods of pollution prevention are (1) process changes, and (2) product changes.*** Various source reduction changes are presented on Figure I-1.

Process changes allow resources to be used more efficiently during the manufacturing process. Process changes include the following:

- Prudent purchasing, in which the company buys the most appropriately sized container of new material rather than buying too much and disposing of the unused portion
- Operational changes, such as reusing input materials during production and reducing water consumption in the process lines
- Technology changes, such as using a safer process material
- Increased energy efficiency

Table I-1 summarizes specific examples of process changes.

Product changes reduce the volume of pollution by reducing the impact of the finished product on the environment. Product changes include the following:

- Development of a less chemical-intensive product
- Development of a higher-quality product that lasts longer
- Incorporation of a life-cycle analysis including the use and disposal options for the product

Other Environmental Management Strategies

There are a numerous pollution control measures that are applied only after wastes are generated. They are, therefore, not correctly categorized as pollution prevention. Table I-2 provides some examples of procedures that are waste management measures but are not pollution prevention.

Companies should recognize that transferring hazardous wastes to another environmental medium is not pollution prevention. Many waste management practices to date have merely collected pollutants and moved them from one environmental medium to another. For example, solvents can be removed from

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TABLE I-1

SOURCE REDUCTION: PROCESS CHANGES

The process changes presented here are pollution prevention measures, because they reduce the amount of waste generated during production.

Examples of input material changes

- Switch to nonsolvent-based coatings and finishes.
- Use a less hazardous or toxic solvent for cleaning, coating, or finishing.
- Purchase raw materials that are free of trace quantities of hazardous or toxic impurities.

Examples of technology changes

- Redesign equipment and piping to reduce the volume of material contained, thereby reducing losses during batch or color changes or when equipment is drained for maintenance or cleaning.
- Change to mechanical stripping and cleaning devices to avoid solvent use.
- Use spray systems with higher transfer effectiveness.
- Install a hard-piped vapor recover system to capture and return emissions.
- Use more efficient equipment.

Examples of improved operating practices

- Train operators.
- Cover solvent tanks when not in use.
- Segregate waste streams to avoid cross-contaminating hazardous and nonhazardous materials.
- Increase control of operating conditions (including flow rate, temperature, pressure, residence time, and stoichiometry) and change maintenance scheduling, recordkeeping, or procedures to increase efficiency.
- Optimize purchasing and inventory maintenance methods for input materials. Purchasing in quantity can reduce costs and packaging material if care is taken to ensure that materials do not exceed their shelf life. Reevaluate shelf life characteristics to avoid unnecessary disposal of stable items.
- Prevent leaks, drips, and spills and use drip pans and splash guards.
- Turn off electrical equipment such as lights and copiers, when not in use.
- Place equipment in a manner that will minimize spills and losses during transport of parts or materials.

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TABLE I-2

WASTE MANAGEMENT STRATEGIES THAT ARE NOT POLLUTION PREVENTION

Off-site recycling

- ! Off-site recycling (for example, solvent recovery at a central distillation facility) is an excellent waste management option. However, because it does not reduce the actual amount of pollution generated, it is not a pollution prevention measure.

Waste treatment

- ! Waste treatment involves changing the form or composition of a waste stream, through controlled reactions, to reduce or eliminate the amount of pollutant. Examples include pretreatment, detoxification, incineration, decomposition, stabilization, and solidification or encapsulation.

Concentration of hazardous or toxic constituents to reduce volume

- ! Volume reduction operations, such as dewatering, are useful treatment approaches, but they do not eliminate or reduce the amount of pollutants being generated. For example, pressure filtration and drying of a heavy metal waste sludge before disposal decreases the sludge water content and waste volume, but it does not decrease the number of heavy metal molecules in the sludge.

Diluting of constituents to reduce hazard or toxicity

- ! Dilution is applied to a waste stream after it is generated. Dilution does not reduce the absolute amount of hazardous constituents entering the environment.

Other control technologies

- ! Control technologies are generally "end-of-pipe" approaches to pollution. Many control technologies that have been used have only collected pollutants and moved them from one environmental medium (air, water, or land) to another. For example, filters that collect paint overspray may prevent air pollution, but they create a solid waste problem.

wastewater using activated carbon. However, regenerating the activated carbon requires using another solvent or heating, which transfers the contaminants to the air. In some cases, this type of waste management strategy is a valid treatment option. However, too often the purpose has been to shift a pollutant to a medium that is regulated less stringently.

For example, waste treatment prior to disposal reduces the toxicity and/or disposal-site space requirements but does not eliminate all pollutant materials. Frequently, the effect is to transfer pollution from air or water to land. Conventional waste treatments include processes such as volume reduction, dilution, detoxification, incineration, and stabilization.

Off-site recycling, which is another waste management strategy, is vastly preferable to other forms of off-site waste handling, because it helps to preserve raw materials and reduce the amount of material that will require disposal. However, compared with closed-loop recycling (reuse) performed at the production site, off-site recycling is likely to have more residual waste that requires disposal. Furthermore, waste transportation and the recycling process carry the risk of worker exposure and release to the environment.

The pollution prevention hierarchy, represented on Figure I-2, prioritizes waste management options from those that are most environmentally beneficial to those that are least environmentally beneficial. Specific technical information on pollution prevention options for the wood finishing industry is in Section II of this manual.

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Section II

Pollution Prevention in the Wood Finishing Industry

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Chapter 1

THE WOOD FINISHING INDUSTRY

The wood finishing industry manufactures a

This manual is targeted mainly toward wood finishing as it applies to the following industries: (1) wood household furniture, (2) wood office furniture, (3) wood kitchen cabinets, (4) wood office and store fixtures, partitions, shelving, and lockers, and (5) any industries closely related to these. Wood finishing companies range in size. Most employ fewer than 50 people. The wood finishing process is often labor-intensive. It usually includes sanding and staining, followed by coating (used interchangeably with "finishing" in this manual), drying, and resanding in repeated steps until the desired finish is obtained. The function of the finishing is to provide the end product with the final appearance and resiliency that satisfies the customer. Facilities vary greatly in product type and quality.

The three grades of furniture—the main product of the wood finishing industry —are often described by the industry as high-end, medium-end, and low-end. Generally, high-end furniture is constructed of solid wood and wood veneers, with the wood grain showing through the finish. A high-end piece might require 30 to 35 finishing operations. Low-end furniture is often made of medium-density fiberboard with some plastic components and some natural wood. The piece often has a colored or printed wood grain finish and might require only six to 12 finishing operations. Figure II-1 shows a typical wood finishing sequence.

In small facilities, wood stock is often moved manually between stations. However, in larger facilities, the wood is moved mechanically along the finishing line. In some cases, pallets—with the wood product on them—are pulled by cables or chains. In other cases, various types of conveyor belts are used. Many facilities use a combination of these methods. Generally, furniture is assembled first; the finish is then applied. Cabinets, on the other hand, are frequently finished before being assembled.

The processes generally involved in manufacturing a value-added wood product -for example, a piece of furniture—include (1) shaping raw stock, (2) assembling parts, (3) applying a finish, and (4) packaging and shipping. Of these processes, application of a finish is the major source of pollution in the wood products industry. This manual focuses on the means of economically minimizing this pollution. Wastes from the remaining operations are mainly nonhazardous. For the purposes of this manual, the wood finishing process is defined to comprise (1) sanding, (2) coating, and (3) the ancillary operations of equipment cleaning and coating preparation.

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Because finishing materials have traditionally been solvent-based, the issue of pollution prevention in the wood finishing industry is closely tied to the issue of reducing emissions of volatile organic compounds (VOC).

The emission of VOCs—including methyl ethyl ketone, methyl isobutyl ketone methylene chloride, toluene, and xylenes—into the atmosphere is the most serious hazardous waste issue currently confronting the industry. Solvents with high VOC content are commonly used in stains, paints, finishes, and glues, in addition to stripping and cleaning operations. The U.S. wood finishing industry is dominated by the use of nitrocellulose lacquers, which—apart from their high VOC content—are hazardous also because of their high flammability.

VOC emissions is the most serious pollution problems.

Most VOC emissions generated by the wood finishing process are from (1) the spray booths, where the coatings are applied; (2) the flashoff areas and ovens, where the finish hardens; and (3) cleanup operations.

Depending on the line of products being manufactured, different sizes and types of spray booths are used. A typical spray booth for a facility manufacturing residential furniture is shown on Figure II-2. Most spray booths of this type are open. Other types of booths are mainly enclosed.

Flashoff areas are either between spray booths or between a spray booth and an oven. Some flashoff areas use forced air circulation to increase solvent evaporation. When fast-drying finishes are used, pieces may be completely cured in these areas. Other finishes may require ovens. Depending on the type of finish used, the ovens are heated to between 38°C and 121°C (100°F to 250°F) or may use infrared or ultraviolet energy sources.

Solvents are often used to clean application equipment, piping, and spray booths, and to strip cured coating from wood parts or equipment. Emissions can be reduced economically in each of these segments of the wood finishing process. Chapter 2 covers various options for pollution prevention. Some options may reduce emissions from several segments of the wood finishing process. For example, changing to a coating material with a lower VOC content will reduce emissions from the spray booth, flashoff areas, ovens, and cleanup activities.

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Chapter 2

POLLUTION PREVENTION OPTIONS FOR THE WOOD FINISHING INDUSTRY

Pollution prevention improves worker health and safety,

The list of pollution prevention options presented in this chapter is extensive but not exhaustive. Research is ongoing in the areas of coating composition and application methods. Also, the best solutions to problems are often original, discovered by creative employees and resourceful management. Additionally, this manual was prepared as an overview of pollution prevention in the wood finishing industry. The manufacturers within the industry vary widely in size and product; consequently, not every option presented will be appropriate for every company. Each company should implement the options that reduce pollution the most while maintaining or improving product quality goals and the company's bottom line. Pollution prevention presents not only an opportunity to improve worker health and safety, and the quality of your environment, but also many opportunities for increased profitability. A manufacturing company's finances may be approximated by the following simple equations:

Product = Raw Material — Waste

and

Income = Product x Price

Any waste produced by a company is potential product wasted. For example, any finish that ends up on the floor instead of on the wood is a raw material that was purchased and could have been part of a finished product; instead, it is merely waste material. Not only is the wasted finish material never sold as part of the product, but it now costs money to clean up and dispose of. Additionally, whether you are in the U.S. or Mexico, this disposal cost will only increase.

As mentioned in Section I, there is a hierarchy of options that deal with waste. The most preferable is source reduction—decreasing the amount of hazardous material used, then recycling or reusing the material, followed by treating the waste and finally disposing of it. Although recycling is not necessarily a method of pollution prevention, some aspects of recycling are covered in this chapter. Source reduction and recycling involve many alternatives. Throughout this chapter, options are given in a roughly descending order of desirability.

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SANDING

Source Reduction

As the cost of raw materials increases, manufacturers must seek more effective uses of timber and veneer. Because thinner veneers are often being used, sanding with minimal stock removal is becoming more important. This has resulted in the use of segmented polishing platens. Platens may be controlled electronically or pneumatically. The electronic sanding platen is more sensitive, but the pneumatic sanding platen is much cheaper. Sanding with air pressure helps to dissipate heat, allowing a more uniform finish at a higher grit without varnishing the panel. Dust collection is important for worker health and for extending equipment life. Without a dust collection system, dust becomes embedded in the sanding belt, thereby shortening belt life and reducing the quality of the finish. Wood dust also tends to work its way into machinery, increasing maintenance costs.

Proper Technique

Paper belts, rather than cloth belts, should be used on hardwoods. ***Paper belts cost about one-half as much as cloth belts and give a better finish, because the abrasive is more uniform on paper belts than on cloth belts.*** Another simple tip for sanding efficiency is to never skip more than one belt. If grit is changed by too much, removing the scratches left by the larger grit will be difficult.

Dust collection systems extend equipment life.

Recycling—Wood Waste to Energy

Traditionally, wood waste has merely been dumped into landfills. Because the cost of disposal will only increase, businesses need to seek more productive alternatives than throwing away so much of their raw materials. Wood waste recycling options include (1) grinding to reduce volume of waste stored; (2) shredding to form animal bedding, mulch, or decorative landscaping; and (3) burning for energy production. ***Wood by-products are a cheap fuel. Consequently, using wood waste as fuel potentially solves two problems: (1) it eliminates problems associated with disposal, and (2) it saves money as an inexpensive fuel source.*** Wood waste, especially waste from unfinished wood, may be used in a wood boiler, typically operating at around 1,600°K, to convert the wood into energy with minimal hydrocarbon emissions. However, burning wood with plastic laminate, containing chlorides, is a problem because of concern over possible formation of chlorinated hydrocarbon. The operator should be familiar with all applicable regulations before a wood boiler is used.

Wood waste can be used for decorative landscaping or

To take full advantage of wood waste as an energy source, a company should automate its feed system to the greatest extent possible. Controlled feeding yields more efficient combustion, and labor costs for hand feeding will only increase. In many cases, there are enough waste and scrap to not only produce enough power for the whole facility, but also to heat or cool the facility. If there are a few small wood finishing operations in one area, it would be possible for these companies to combine wood waste so that they could have sufficient quantities to generate power or to sell or distribute for other purposes.

FINISHING

Variations in the finishing procedure are too numerous to list exhaustively, but wood finishing usually consists of some combination of the following materials being applied in the following order:

1. Size, coat and/or bleach to prepare the wood and ensure uniform color
2. Stain to achieve the desired color
3. A washcoat to smooth the wood
4. Filler, fill-glaze, or oil sealer
5. Wood sealers
6. Glaze and/or shading stains
7. Topcoats

Each of these materials is available in various general formulations. For example, stains, sealers, and topcoats are available in water-based and nitrocellulose-based formulations. This section will discuss these general types of formulations, rather than individual materials (such as stains, sealers, and fillers).

The most significant source of pollution in the wood finishing industry is the VOC content of the finishes used to provide the product's final appearance. Two main areas to consider when developing your pollution prevention plan are the materials of which your coatings are made and the application methods used. The type of coating is important, because available materials vary widely in their VOC content—the lower the VOC content, the less pollution will be generated. Application methods are also very important—the better a process transfers the coating to the wood, the more money a company will save and the less pollution it will generate.

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Source Reduction

Alternative Coatings

Switching to a different coating material can reduce or even possibly eliminate hazardous waste. It requires a strong organizational commitment to change finishing materials. Such a change, however, can eliminate many health and environmental problems and result in a comparable or even superior finish. Of course, not every alternative finish is right for every product. Time must be spent to find the acceptable alternative. This section first discusses the properties of traditional nitrocellulose-based coatings and then presents several types of alternative coatings.

<u>Nitrocellulose-Based</u>

Choosing the best finish is important for environmental

Nitrocellulose-based coatings are by far the most frequently used type of finish in the U.S. wood finishing industry. The properties of nitrocellulose-based coatings are presented here to establish a standard against which the alternative coatings may be judged.

Nitrocellulose is a resin that acts as a binder in the coating material. Different types of organic solvents must be mixed with nitrocellulose. Some solvents are added because of their evaporative properties, and some are added because of their ability to dissolve the nitrocellulose. This blend causes the coatings to dry quickly and gives them a desired viscosity. Nitrocellulose coatings are nonconvertible coatings, meaning that film formation occurs via solvent evaporation—no chemical reaction, or curing, takes place. The resulting finish has low resistance to heat and solvents. Because of this, the finishes are easy to damage and relatively easy to repair. Nitrocellulose-based coatings are classified as fast-drying. They contain about 6 pounds of VOCs per gallon of coating, not including water. The solids content of the nitrocellulose-based lacquers is about 16 percent by volume. This relatively low solids content is necessary to achieve the needed viscosity.

Finishing with nitrocellulose-based coatings is a familiar, well-developed procedure. Nitrocellulose coatings are (1) easy to apply, (2) dry quickly at ambient temperature, and (3) perhaps most important—produce the final appearance that manufacturers believe customers want. However, these coatings have several major drawbacks. ***First, nitrocellulose is highly flammable. Second, it requires the use of organic solvents that are expensive, toxic, and quick to volatilize. Finally, the resulting finish is not very durable, and it yellows in sunlight.*** Switching to alternative coatings has many benefits. However, when considering a switch, an organization must remember to adapt its equipment; perhaps even more important, it must adapt its personnel training to the new finishing material.

Waterborne

Waterborne coatings may be the future of the industry.

Waterborne coatings are widely considered the future of the wood finishing industry. There are many types of water-based coatings. What all of these coatings have in common is that water is the major solvent or carrying liquid for the film-forming polymers. Within waterborne coatings are three types of polymer systems: (1) water emulsions, (2) water-reducible resins (solutions), and (3) colloidal dispersions. Coatings formulated with water-emulsion polymers contain water-insoluble spherical particles of high molecular weight uniformly dispersed in water. Water-reducible resins are completely soluble in water or water-solvent mixtures. Colloidal dispersions contain medium molecular weight polymers that combine the properties of the water-emulsion polymers and the water-reducible polymers.

Depending on the type of polymer in their formulation, each type of waterborne coating exhibits different film properties. Understanding the advantages and disadvantages of each type makes coating selection easier. Water-emulsion formulations produce finishes that are durable and stain-resistant.

Water-reducible formulations offer high gloss, clarity, and good application properties. However, the film is not as durable as the water emulsions. Viscosity depends on molecular weight, making the water emulsion formulations the most viscous. Colloidal dispersion formulations offer high gloss, good application properties, durability, and resistance to chemicals and staining. Different waterborne coatings require a different drying method; some require air or forced air, and others require elevated temperature.

The VOC content of water-based coatings varies substantially. Cosolvents are usually added to allow adequate coalescence and film formation, and aid penetration of pigmented materials. Most waterborne coatings have a VOC content of from 1.3 to 2.3 pounds per gallon, less water. The coatings range from 26 to 30 percent solids by volume. ***These waterborne finishes represent a 90 to 95 percent reduction in VOC emissions per volume of solids applied.*** The total emission reduction for a facility depends on how many steps, formerly using nitrocellulose coatings, can be converted to using water based finishes. The major disadvantage of water is that it evaporates at a slower rate than solvents.

Each type of coating material is associated with a different set of concerns. The following factors that should be considered when using waterborne coatings:

- ! Waterborne coatings should generally be stored at temperatures above freezing.

- ! Equipment must be cleaned immediately after use, because the dry coatings are no longer water-soluble.

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- Sagging and grain raising are potential problems that must be addressed.

- Equipment pumps, containers, and application equipment should be corrosion-resistant.

- Humidity has a large effect on the drying rate and must be accounted for.

- Current water-based finishes are available and satisfactory for most applications, but there are often subtle differences in the final appearance.

- Waterborne coatings are generally more susceptible to air entrainment; consequently, aeration should be minimized by returning coating material to the tank below the fluid level and minimizing the splash caused by agitators.

- For the coating to adhere well, surfaces must be free of oil films.

Today, Waterborne formulations give finishes comparable

Equipment can be cleaned with soap and water.

Waterborne finishing materials are used by a growing number of companies. Water-based coatings are generally 25 to 50 percent more expensive than traditional materials, but—because they have twice the solids content—they are at least as cheap to use. In the past, the water-based coatings were suitable only for low-end products. The first water-based finishes had problems with grain raising and with clarity, but these problems are diminishing as new formulations are generated. Waterborne lacquers are now durable and offer good clarity and sandability. ***Water-based finishes currently offer many benefits over conventional nitrocellulose lacquers, including (1) greater resistance to moisture, chemicals, impact and reverse impact, and abrasion, (2) adaptability to a wide range of application methods, (3) low toxicity, (4) low VOC content, and (5) cleaning of equipment with soap and water.*** Waterborne coating can usually be applied with the same methods as traditional solvent-based finishes. ***The main cost of conversion is for installing corrosion resistant equipment. An added incentive is the decrease in insurance costs that results from switching to a water-based system. Insurance for facilities that use only water-based coatings averages 50 percent less than for shops that use solvent-based formulations.***

Polyester

Nitrocellulose lacquers dominate the U.S. wood finishing industry. However, this is not the case in all countries. In other parts of the world, polyester-based and polyurethane-based coatings predominate.

Two types of polyester coatings are available. The first type is a styrene-derived polyester. Here, styrene is used as a solvent and reactant for unsaturated alkyd resins contained in the coatings. The formulations also contain a drying agent, usually a heavy metal, and may be cured through a catalytic reaction or by ultraviolet (UV) radiation. Acrylic polyesters comprise the second type of polyester coatings. These contain organic solvents and cross-linking acrylics. They are cured either by catalytic reaction or exposure to UV radiation.

Both types of polyester coatings are fast-drying with films that are durable and resistant to heat, chemicals, and impact. Because the polyester films are so durable, they are also very difficult to repair after curing. Styrene-based polyesters are ***usually 100 percent solids VOC emissions of near zero. The acrylic polyesters have a VOC content of about 3 pounds per gallon, less water, with a solids content of 30 to 50 percent by volume. Each step converted from nitrocellulose-based coatings to*** polyester coatings would result in an 85 to 100 percent reduction in VOC emissions. However, polyester finishes are chemically incompatible with nitrocellulose; mixing these compounds is a potential explosive hazard. Polyesters and nitrocellulose finishes should never be used on the same piece. The aesthetic and chemical compatibilities of different coatings should always be considered before coating types are mixed on the same piece.

Polyurethane

As with polyester coatings, polyurethane finishes are used infrequently in the U.S. but are common in other countries. Polyurethane coatings are formed through the reaction of a polyhydric alcohol with an isocyanate cross-linking resin. Classification of polyurethane finishes depends on the formulation or cure process, as follows: (1) one-component products, (2) two-component products, and (3) moisture-cured materials. The two-component products are convertible coatings; film formation occurs through polymerization. Moisture-cured coatings are not fully cured through polymerization; rather, the final curing occurs when moisture in the environment reacts with the material to form a dry film. Moisture-cured coatings can take up to several months to cure. Once cured, all polyurethane coatings are very durable and are characterized as good for polishing, providing a high-gloss finish. As with polyester finishes, the high durability of polyurethane coating means that it is very difficult to repair after curing.

Within the last few years, a two-component waterborne polyurethane resin has been developed. It combines the finish properties of the traditional solvent-based polyurethanes with the advantage of a zero VOC content. The traditional polyurethanes have a VOC content of about 3.4 pounds per gallon, less water. They are between 40 and 60 percent solids by volume. ***Overall, traditional polyurethanes would represent about an 80 percent reduction in VOC emissions***

from those of nitrocellulose-based finishes. As with all coating types, the overall pollution reduction depends on how many steps could be converted to the alternative coating.

Carbon Dioxide (CO_2)-Based

Union Carbide has developed the Unicarb™ coating system for minimizing VOCs. ***This system uses supercritical CO_2, instead of organic solvents or water, to dissolve the coatings.*** The Unicarb™ coatings contain polymers and coalescing solvents, whereas the cutting solvents are omitted. In most formulations, cutting solvents are used to decrease viscosity and enhance atomization. The Unicarb™ system uses CO_2 to decrease viscosity and enhance atomization. The viscous coating and supercritical carbon dioxide are blended in a mixing chamber. Generally, compared to traditional coatings, 1 pound of carbon dioxide "replaces" 1 pound of cutting solvents. The mixture is released as an atomized paint through an airless spray gun. The CO_2 evaporates from the atomized coating. The deposited paint, still containing the coalescing solvents, cures conventionally, either by air drying or baking. The quality of the atomized coating is considered superior to conventional airless atomization and similar to that obtained by conventional air atomization.

The Unicarb™ coatings contain about 4.7 pounds per gallon, less water, of VOCs and they are about 34 percent solids by volume. ***Overall, VOCs are reduced by about 50 percent.*** The exact properties depend on the type of coating used in the system. A company using the Unicarb™ system has the advantage of not having to completely reformulate its finishes, while it is still reducing VOC emissions. ***A nitrocellulose Unicarb™ coating, for example, will produce a film with the same advantages and disadvantages as the traditional film but will have lower VOC emissions.*** The main disadvantages of Unicarb™ are the lack of demonstrated performance by manufacturers and the royalties that must be paid.

Ultraviolet (UV)-Curable

UV curing is good for flat pieces.

The main components of UV-curable coatings are polymers, diluent monomers, and photoinitiators. UV curing uses high-intensity UV light to react with the photosensitizers, thereby creating free radicals that initiate crosslinking to form the solid film. Consequently, UV-curable coatings are convertible. Much of the diluent is also polymerized to become part of the film. Curing is rapid, and the final film is durable. For these formulations, UV radiation is used to effect chemical and physical change in the organic coating materials by the formation of crosslinking in the coating polymers.

Because most or all of the components react to form the coating, UV-curable coatings are often considered to contain up to 100 percent solids. Some UV coatings contain some conventional solvent, and ***the overall reduction in VOC***

emissions is from 80 to nearly 100 percent. Curing three-dimensional pieces remains difficult, because all of the finish must be exposed to the UV radiation. Some UV ovens have been designed to accommodate three-dimensional pieces. However, because the UV lamps need to be arranged for each type of furniture, these ovens would be practical only for a product line that manufactured the same design for a reasonable length of time. Currently, UV curing is still used mainly for flat products. However, the curing is rapid, and the product is heated little during curing, resulting in higher productivity and lower space requirements. Curing also uses less energy than thermal curing. UV curing will typically use one-fifth of the energy used by a comparable thermal curing line. Energy is absorbed only by the coating and is not wasted by heating the air or workpiece. All UV coating materials are, basically, single-component systems that do not require the addition of catalyst. UV curing is one form of radiation curing; radiation curing is also accomplished by using infrared radiation and electron beams. The cost of a UV curing system varies from $4,200 to $200,000.

Table II-1 shows overall reductions in VOC emissions possible for each step where nitrocellulose-based coatings are replaced by an alternate coating. The total VOC reduction depends on how many steps can be converted to using an alternate coating material.

TABLE II-1

REDUCTIONS IN VOC EMISSIONS POSSIBLE FOR EACH STEP WHERE NITROCELLULOSE IS REPLACED WITH AN ALTERNATIVE COATING

Coating Material	Percent Reduction in VOCs
Nitrocellulose	0%
Water-based	90 - 95%
Polyester	85 - 100%
Polyurethane	80 - 100%
CO_2-based	~ 50%
UV-Curable	80 - 100%

Table II-2 summarizes the advantages and disadvantages of each type of coating.

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TABLE II-2

COATINGS

Coating	Advantages	Disadvantages
Water-based	! Durable ! At least as cheap to use as conventional coatings ! Low VOC content ! Equipment cleans with soap and water ! Decreased insurance costs, because fire hazard is eliminated ! Lower volume of material to store	! Need for corrosion-resistant equipment ! Evidence of grain raising on some types of wood from some formulations ! Possible need for air movement or heat to facilitate drying ! Surface must be free of oily films ! Higher viscosity, possibly requiring changes in piping and pump system ! Need for better temperature and humidity control
Polyester and Polyurethane	! High gloss ! Very durable ! Low VOC content	! Difficult to repair ! Requires a "clean room" environment
CO_2-based	! Low VOC content ! Elimination of the cost, odor, flammability, toxicity, and oven sagging associated with cutting solvents	! Royalty costs ! Special sprayer and delivery system needed ! Pumps and mixers required to handle the viscous Unicarb™ formulations ! Limited industrial experience
UV-curable	! Low energy costs ! Very low VOC content ! Very durable finish ! Rapid curing	! Higher coating costs ! Difficult to cure irregular-shaped pieces ! Limited to clear or semiclear finishes and thin films
Nitrocellulose	! Established methods ! Easy repair ! Fast drying	! Average to poor durability ! High VOC content ! Toxic and flammable

Application Methods

The following techniques are used for coating applications: (1) flat line finishing, (2) spray application, (3) brushing, and (4) dipping. Within each technique there are many variations. Flat line finishing is used to coat only flat stock. Dipping is usually not used for hollow pieces. Spraying is the most commonly used technique. One way of measuring the efficiency of coating usage is to examine transfer efficiency (TE). TE is defined as the ratio of the solid coating deposited on a surface to the total amount of coating used, expressed as a percentage. For example, if one-half sprayed of the coating stays on the target, the system has a TE of 50 percent. Although 50 percent TE is almost twice that usually achieved by conventional spray guns, one-half of all material purchased is still wasted. Examples of savings from improved TE (for example, by better equipment or operator training) are shown in Table II-3.

Low transfer efficiency = money wasted.

Electrostatic

During electrostatic finishing, coating particles are atomized and given a negative charge, whereas the piece to be finished is either grounded or given a positive charge. Electrostatic attraction pulls the particles to the product. This attraction results in a high TE, which allows each piece to be finished with fewer passes, thereby using less coating material and saving time and money. The main advantage of using this type of system is the high TE. One effect of electrostatic finishing responsible for increased TE is called "wraparound." This is the tendency of the charged coating particles to effectively cover the sides of the piece being sprayed and even for particles that go past the piece to be attracted to the back of the piece. Another property of electrostatic finishing, the Faraday cage effect, causes the particles to deposit only around the entrance of a cavity, often making touchup painting necessary. The particles must possess sufficient momentum to overcome the Faraday cage effect but not so much that the attractive forces are completely negated. Therefore, balancing particle velocity with electrostatic voltage is essential to optimizing TE. Another consideration is that the workpiece must be a conductor. Obviously, this is no problem for metal finishing, but it is a concern for wood finishing. When the wood has a sufficient moisture content, it is a reasonably effective conductor. However, when the wood is very dry, it does not conduct well enough on its own. Nonconductive surfaces must be treated with a coating that increases the electrical attraction between the charged coating particles and the piece to be finished. One common type of treatment is to apply sensitizers to the wood surface. Sensitizer formulations are applied in a thin colorless film that picks up moisture from the surrounding air. This moisture makes the piece conductive enough to spray electrostatically and the sensitizer dissolves into the applied coating. Using a sensitizer is a process that is sensitive to humidity and is not

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TABLE II-3

SAVINGS PER $1,000 SPENT ON COATING MATERIALS WITH IMPROVED TRANSFER EFFICIENCIES (TE)

Old TE	New TE 45%	50%	60%	70%	80%	90%
20%	556	600	667	714	750	778
25%	444	500	583	643	688	722
30%	333	400	500	571	625	667
35%	222	300	417	500	563	611
40%	111	200	333	429	500	556
45%	0	100	250	357	438	500

Note:

Example—A company uses 100 gallons of finish per month spraying cabinet doors ($10 per gallon for a total of $1,000). The conventional spray guns that the company uses are 30 percent efficient. If company switches to an air-assisted airless spray system which is 60 percent efficiently, the company would save $500 per month.

effective when relative humidity is below 40 percent. The rewards of using electrostatic finishing may be worth the effort, however, because the coating cost may be reduced by about 40 percent.

The two main types of electrostatic equipment are rotary atomizers and electrostatic spray guns. Some rotary atomizers use rotating disks, and others use balls. Disks are best for long thin parts and flat pieces, whereas balls are better for shorter, wider pieces. Low-speed rotary atomizers rely on electrostatic force to atomize the coatings, whereas the high-speed versions use centrifugal force to atomize the coatings. Both apply a negative charge to the particles. Electrostatic spray guns may be of either the air or airless variety. These spray guns operate in a manner similar to that of conventional guns, using air or fluid pressure for atomization. Additionally, the particles are charged by an electrode at the tip of the gun. The overall TEs are generally better with the rotary atomizers than with the electrostatic spray gun. Electrostatic spray guns produce particles with greater momentum, tending to increase overspray. Also, they are less efficient at electronically charging the paint particles than the rotary atomizers. Electrostatic spraying equipment can cost over $60,000 and, consequently, may be too expensive for smaller shops.

High-Volume/Low-Pressure (HVLP) Spray

HVLP spray guns use a high volume of air at low pressure—no greater than 10 pounds per square inch (psi)—to atomize a stream of coating material. At low pressures, coating materials are propelled at lower velocities than with conventional systems. At these lower velocities, "bounce-back" is minimized, and TE is improved. This softer spray is also good at penetrating recessed areas. However, this higher TE is achieved at the cost of a lower fluid flow rate. ***The finish achievable with HVLP is comparable to finishes with conventional spray, when***
low- to medium-viscosity coatings are used. As with all spray gun techniques, TEs depend on operator skill level, type of equipment, coating formulation, and operating pressure. **HVLP systems typically have TEs in the *40- to 70-percent range***. As described in a later section, operator skill level is the most reliable predictor of TE. Nevertheless, it is also vitally important that gun performance is optimized, for example, with proper system pressure and the optimal spray gun tip.

Increasing transfer efficiency from 30% to 60% will cut

There are two basic types of HVLP systems; one is operated with a compressor; the other is operated with a turbine. When a compressor is used a conversion kit is purchased to allow the use of HVLP. This kit contains filters to clean the air and a regulator to control air pressure. Turbines are ideal for use with HVLP systems, because they are designed to produce a high volume of warm, dry, low-pressure air. The heated air produced by most turbines can improve the ability of coating to flow and speed drying.

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Airless Spray

As the name implies, this method of atomizing coatings does not use compressed air. Instead, hydraulic pressure is used to force the material through the small opening of the spray gun nozzle to atomize the coating. The system can be adjusted either by adjusting the viscosity or changing the fluid pressure. Airless systems have several advantages. First, airless systems have better TEs than conventional systems. Second, when heavy films are desirable, a single coating with airless spray often yields results that would require two coats, applied conventionally. Also, because the airless guns deposit material faster, a gun may be moved faster to produce a given film thickness. ***This results in greater productivity and less operator fatigue. Other reported benefits are (1) fewer rejections, because of a more consistent finish, and (2) as much as 15 percent savings in material costs.***

Although materials do not need to be reformulated for use with an airless system, heating the coatings is one way to improve the system. Heating coating materials for an airless system provides three main advantages: (1) because of increased atomization, finer finishes are possible; (2) because of the lower viscosity of heated liquids, hydraulic pressures necessary for atomization may be lowered, and (3) the heated spray facilitates solvent evaporation for faster drying. The main disadvantage of airless spray is that the quality of the finish is usually lower than with conventional spray. This is not true in applying thicker coats, however, in which airless spray is quite effective.

Air-Assisted Airless Spray

In an air-assisted system, air jets assist in the final break-up of a pressurized liquid stream. Air-assisted, airless spray systems use a pressurized stream of coating, as with airless spray, with air jets assisting in the atomization of the coating material. This system wastes less paint and achieves a higher quality finish than an airless spray. In fact, the finish achieved with air-assisted airless spray is comparable to the finish obtained with conventional air spray, and ***a 5 percent reduction in annual feedstocks has been documented.***

Vacuum Coating

Vacuum coating is another application method with a TE of near 100 percent, but it is also limited in the shapes of pieces that it can accommodate. The application is performed in a coating chamber. This chamber has openings on opposite sides that are the same shape as, but slightly larger than, the piece to be finished. Coating material fills the chamber to above the openings. Because the chamber is under a vacuum, coating material does not spill out of the openings. The workpiece is passed through the chamber. After the workpiece exits the chamber, a stream of air removes the excess finish. Film thickness is controlled by varying the coating's viscosity, the magnitude of the vacuum, and the intensity of the air jet. The major limitation of this technology is that it can accommodate only pieces possessing the same silhouette dimensions over the entire length of the part. The system is intended mainly for use with waterborne coatings, because the vacuum would tend to deplete solvent-based finishes.

A few advantages that a company could receive from using this technology are (1) significantly lower material costs, resulting from very high TE, (2) improved coating quality, (3) higher productivity, and (4) lower direct labor costs.

Flat Line

As the name implies, flat line finishing is the coating method of choice for finishing essentially flat workpieces. Prior to finishing, the pieces are sanded to uniform thickness, and a filler is applied to function as a base for the subsequent coatings. Roll coaters apply the finishes and are often engraved to produce a wood-grain effect on panels made from particle board. Applying the finish with rollers results in a very high TE and allows the use of high solids coatings that are difficult or impossible to spray. UV curing is an excellent option after flat line finishing, because it is efficient at curing flat pieces. If a company manufactures flat pieces, it can use materials much more efficiently, with significant savings, by converting from conventional spray finishing to flat line finishing or another technique designed for flat pieces, for example, curtain coating or vacuum coating.

Curtain Coating

Curtain coating, or "pouring," is a high-speed production process for applying smooth films to flat or moderately curved workpieces. This is related to the older principle of flow coating—moving an object through a continuous falling stream of material. In curtain coating, however, the piece is passed through a pressure head or over a weir-head at very high production rates, about 150 meters per minute. The excess coating material is trapped in a reservoir and recirculated with minimal losses.

Dipping

Dipping is another direct application technique. A workpiece, which may be of any shape, is submerged in a tank of the desired coating material. The object is removed from the tank, and the excess is allowed to drain back into the coating tank. It is crucial that the viscosity of the coating material be optimized to achieve the desired film thickness. It is also vital that the piece be allowed sufficient time for excess material to drain off while the piece is still above the tank. Without sufficient time, material will be wasted.

Choice of appropriate coating methodology will

In summary, various acceptable application methods are available, and every organization should evaluate its application methods periodically and make modifications when necessary. Table II-4 summarizes the advantages and disadvantages of the various application methods.

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TABLE II-4

APPLICATION METHODS

Application Technologies	Advantages	Disadvantages
Conventional Low-Volume/ High-Pressure Spray	! Excellent atomization ! High production rate	! Extensive overspray—poor TE ! Booth cleanup costs ! Filter replacement costs ! Hazardous waste disposal costs ! High VOC emissions
HVLP Spray	! Low overspray and good transfer efficiency ! Reduced waste ! Lower booth cleaning costs ! Lower filter replacement costs ! Decreased VOC emissions ! Lower worker exposure	! Less complete atomization ! Need for clean dry air ! Slower application rate
Air-Assisted Airless Spray	! Good atomization ! Good transfer efficiency	! Increased maintenance ! Increased training required ! Skin injection dangers
Airless Spray	! High coating flow rate ! No air hose ! Good transfer efficiency ! Able to handles viscous fluids	! Reduced spray pattern coated ! Relatively poor atomization ! Skin injection danger ! Increased training and maintenance required
Electrostatic Spray	! Good transfer efficiency ! Uniform film thickness ! Edge cover	! Bulky delicate guns ! High equipment and maintenance costs ! Faraday cage effect ! Importance of cleanliness ! Safety and fire hazard ! Part must be conductive ! Cost
Electrostatic Rotary Atomizers	! Excellent atomization ! Excellent transfer efficiency ! Handles any type of finish ! Uniform film thickness	! Faraday cage effect ! Importance of cleanliness ! Safety and fire hazard ! Parts must be conductive ! Cost
Dip Coating	! High production rates ! Low labor costs ! Excellent transfer efficiency	! Importance of coating viscosity ! Not suitable for hollow pieces ! Fire hazard ! Below-average appearance
Flow Coating	! Excellent transfer efficiency ! High production rates ! Low labor costs ! Low maintenance	! Below-average appearance ! Importance of coating viscosity
Curtain Coating	! Excellent transfer efficiency ! Uniform film thickness ! Very high production rates	! Viscosity-dependent ! Only for flat work
Vacuum Coating	! High production rates ! Excellent transfer efficiency ! Lower labor costs	! Suitable only for pieces with uniform silhouettes ! Based for use with waterborne coatings

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Application Technique

Because spray painting allows fast and even coverage with relatively low labor costs, it is often the application method of choice in the wood finishing industry. However, applying coatings with a spray gun tends to waste much more material than brushing, rolling, or dipping, which typically have TEs of over 90 percent. Conversely, spray application can result in TEs of as low as 20 percent. Any coating material that does not stay on the product is wasted. ***If the TE of a system is 30 percent, you are wasting 70 percent of your money spent on coating materials!*** Many factors affect TE, including (1) spray equipment type, (2) equipment maintenance and optimization, (3) size and shape of the target, (4) type of coating, (5) air pressure and velocity, and (6) fluid flow rate. One way to improve TE is to use the spray equipment as it was meant to be used. People frequently increase air and fluid pressure beyond recommended limits. This produces a mist that is easier for unskilled workers to apply uniformly. Unfortunately, high velocities increase bounce-back, and the ventilation system tends to carry off most of the coating mist, resulting in low TEs. Consequently, overspray is directly related to air and fluid pressure; these pressures should be as low as possible. Figure II-3 shows typical TEs of various application methods.

Material that does not stay on product is material wasted.

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Air and fluid pressure and spray gun type are very important; however, according to a 1992 study by the Pacific Northwest Pollution Prevention Research Center, the factor most consistently influencing TE is the skill level of the operator. ***Therefore, training operators in proper spray technique is the easiest way to significantly decrease pollution and save money.***

Proper Spray Technique

The following are fundamentals of good spray technique:

- Fifty percent overlap of the spray pattern
- Spray gun held 6 to 8 inches from the workpiece
- Constant gun speed of about 250 feet per minute
- Holding the spray gun perpendicular to the workpiece surface
- Triggering the gun at the beginning and end of each pass

Good training is the easiest way to save money.

If less than a 50 percent overlap is used, the workpiece will become streaked.

If more is used, coating material is wasted, and the operator makes more passes than necessary to finish the piece, requiring excessive time spent on each piece. To maintain a 50 percent overlap, the painter, on the first pass, aims the spray gun nozzle at the edge of the workpiece. On each subsequent pass, the painter aims the spray gun at the bottom edge of the previous pass.

The distance between the spray gun and the workpiece must remain constant for a uniform finish. A separation of 6 to 8 inches is usually ideal. As the separation increases, the width of the spray pattern on the workpiece increases, and the thickness of the film decreases. Also, a separation of more than 8 inches often results in some of the finishing material drying before it reaches the surface. This dry material either bounces off the surface, thereby wasting material, or sticks to the surface, thereby producing a grainy finish. Spray guns should be adjusted for the separation that will be used, and operators then need to maintain that distance.

A consistent finish also requires a constant gun speed. Changing the speed varies the amount of material being applied to the surface. Low gun speeds may result in the application of too much finish, causing runs. High gun speeds may result in poor aiming, improper gun control, and a distorted spray pattern. All of these demonstrate inefficient use of materials. Gun speeds that are too high may also lead to inadequate coating thickness.

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Maintaining the gun perpendicular to the surface is also important. Failing to hold the gun perpendicular to the workpiece results in uneven coating, and the increased angle of incidence of the spray increases the amount of material that rebounds off the surface. Arcing or fanning the gun constantly changes the gun distance and the gun angle, making a uniform finish unlikely.

Training Operators

A company can derive the following benefits from a formal training program for spray operators:

- Reduced material costs
- Higher quality finish
- Reduced VOC emissions
- Less overspray and reduced cleanup costs
- Higher production rate

Training is often conducted on the shop floor by a coworker who shows spray techniques to a new operator. This method of training is inefficient at best. The trainee will often pick up and repeat the bad habits of the coworker. Also, the coworker will often neglect to convey important points that seem obvious to an experienced operator but are not obvious to a new employee.

Formal training, however, should include an explanation of the fundamentals of good spray technique and how these techniques can benefit the operator. First, good technique makes the job easier for the operator. Through proper spraying, the operator can spray the piece faster and use fewer strokes. For example, if an operator can reduce the number of strokes needed to finish a piece of furniture by just five, and the operator sprays 200 pieces each day, the operator would save 1,000 strokes per day. Second, good spray technique will result in a higher quality finish. Generally, people take pride in their work and will appreciate the opportunity to make a better product.

Ideally, each operator should be videotaped periodically. The operator should then meet with the supervisor and technical personnel to review the tapes. Because spray operators are usually very knowledgeable, they can often identify poor techniques by watching themselves on tape. Constructive advice and "hands-on" instruction under production conditions should follow the videotape review. Next, the operators should be retaped and given an opportunity to compare the two tapes. This allows the operators to see their improvement. ***One company, conducting this training twice a year, reported an 8 to 10 percent reduction in the amount of finishing material being used, resulting in annual savings of $50,000 to $70,000.***

Proper supervision will ensure that principles learned in

Even with good training, supervision is necessary to ensure that operators do not revert to bad habits. To maximize TE, regardless of the type of system used, excessive air or fluid pressure must be avoided to maximize TE.

Also, training must be specific to the equipment and materials being used. For instance, because of their higher solids content, waterborne coatings do not need to be applied as thickly as solvent-based finishes.

Operation and Maintenance

Direct Transfer of Coatings to the Spray Guns

A system that transfers coatings directly to the guns, instead of by hand with a bucket, offers many advantages. It may be economically justified even if your shop uses as little as 30 to 40 gallons a week.

A direct transfer system eliminates the need to fill a can from a drum each time a coating is needed. The following savings can be expected:

- Discounted costs from bulk purchases
- Less material waste from minimizing spills, evaporation, and loss of skimmings on the side of the drum
- Lower labor costs because of less time spent collecting paint from the storage area, adjusting the coating's viscosity, and filling pressure pots and gravity containers
- Lower solvent costs, because containers no longer need to be cleaned at the end of the shift

The savings in time increase productivity. ***Finish quality is also improved, because the finishing material that reaches the gun is more consistent.***

The three main types of transfer systems are (1) dead-end, (2) simple flow, and (3) fully recirculating. A dead-end system merely supplies the material to the end point with no return line. This type should be used only for materials in which settling is not a problem. A simple flow system has a return line to the storage tank from the farthest point of use. This continuous circulation prevents settling in most materials. The fully recirculating transfer system is designed to circulate the material even in the hose of the spray gun. This type of system is used only for coating materials with very high settling rates.

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Caring for Spray Equipment

All equipment, especially the spray equipment, must be maintained regularly to minimize replacement costs and optimize performance. This, in turn, helps prevent pollution. The following measures, among others, will help ensure reliable spray operations:

- Place compressor where it gets fresh air, and clean and lubricate it regularly.
- To avoid spray gun clogging, keep feed tanks free of dried finish particles by cleaning them properly, and use proper agitation to prevent skin from forming.
- Never mix air in material hoses.
- Optimize selection of needle, nozzle, and air cap for each type of finish.
- Do not spray lacquer and varnish in the same booth, because this can result in spontaneous combustion.

Treat equipment as if it is your own.

Use Heat Instead of Solvents to Thin Coatings

The viscosity of coatings must often be adjusted before the coating can be sprayed. Traditionally, this has been accomplished by adding organic solvents. ***The cost of solvents is a significant part of the overall cost of materials, and solvents are sources of air pollution. An alternative to solvent thinning is to use heat to reduce coating viscosity.*** Benefits include lower solvent usage, fewer emissions, viscosities that are more consistent, and faster curing rates.

Thinning with heat means faster curing.

Closed-Loop Recycling of Lacquer

HisStrand Chemical of Lenoir, North Carolina, has developed a method of recycling lacquer dust. For this program, the dust must come from conventional nitrocellulose lacquers. Lacquer dust is the flammable overspray residue in spray booths, on baffles, and in filters. ***The only cash outlay required is a sifter, which can be bought for about $1,500. Depending on the size of the facility, this cost can typically be recovered in a few weeks to a few months.*** The process is closed-loop recycling, the lacquer dust is eventually resprayed onto product. The lacquer dust becomes a basic ingredient in formulating the sealers, and coatings for backs and drawers. Usually, each pound of lacquer dust yields 1 gallon of sealer. ***This reduces disposal costs and material costs, with a minimal change in labor costs.***

Recycling nitrocellulose lacquers saves

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Inventory Management

Improved inventory control can reduce costs and minimize waste. If too much finishing material is purchased, (1) the production of that piece could end, leaving a large quantity of material unused, and (2) the material may deteriorate before it can be used. Companies should work with their suppliers to accurately determine inventory needs so that excess is minimized. Stock stored beyond its shelf life, or stock that becomes unusable because production has been completed, results in two preventable costs: (1) costs from unneeded material purchase, and (2) costs associated with disposal of the waste material.

If there is excess finishing material at the end of a production run, a company has several options. The best option is, obviously, to find another project on which to use the material. Other options include (1) returning unused containers to the original vendor, (2) contacting other finishers about their potential needs, and (3) contacting a waste or materials exchange. Options for managing waste or excess solvents are shown on Figure II-4.

Recycling

Recycling solvents by purifying through distillation is an attractive alternative that will reduce material cost and minimize waste. Distillation is a proven technology with equipment available in a variety of sizes. It may be performed on site or by off-site vendors. On-site recycling that occurs as part of the coating process, closed-loop recycling, is considered a pollution prevention technique. An example of closed-loop recycling is recovering coating material from, and returning it directly to, an application unit. Another option to extend solvent life is to remove particulate matter from the solvent by settling or filtration so that the fluid may be reused in a rough cleaning of materials.

Another form of on-site recycling is capturing overspray in the spray booth and returning it to the process. A water wall flowing over a series of baffles at the back of the spray booth can capture overspray from the air. The coating and water mixture forms a sludge. If the coating material is immiscible with water, the coating can be easily separated and recycled. If the coating material cannot be easily separated from water, ultrafiltration can be used to separate the water from the coating material. Ultrafiltration uses membranes with small (about 0.01-micron) pores to filter the mixture. Water passes through the membrane, but coating particles are too large to pass through the membrane pores.

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EQUIPMENT CLEANING

Equipment cleaning is required when a process is completed, a color change is needed, or maintenance is required. When assessing the pollution prevention opportunities in the cleaning process, a facility should use good operation practices to minimize the frequency of cleanings. For instance, production may be sequenced so that pieces requiring light-colored paint or stain are sent through the finishing line first, followed by the pieces that require darker finishes. This minimizes the need for cleaning between runs. Also, it should be determined whether cleaning is even necessary. For some low-cost items, the cost of replacing the item may be less than the costs associated with cleaning solvent, solvent waste disposal, and additional labor. However, the cost of properly disposing of the item must be considered.

When cleaning is necessary, facilities should incorporate mechanical cleaning (scraping and wiping) into cleanup procedures. Floors should be cleaned with squeegees instead of rags, brooms, or mops. Where possible, Teflon-lined tanks can be used to improve drainage and reduce coating deposits. When tanks are cleaned, operators should use rubber wipers to manually scrape the sides to remove coating deposits.

Leave containers open, and watch your profits evaporate!

If cleaning with solvents is necessary, alternative solvents are available, the use of which results in lower VOC emissions than the use of conventional solvents. Dibasic esters are one class of alternative solvents. Solvents with low volatility should be used to minimize emissions. When conventional solvents are used, there are still a few options that reduce pollution and save money. The easiest and most obvious way is to fully use the solvents that are purchased. Most companies dispose of their solvents long before they should do so. ***Solvents should be disposed of or recycled only because they have lost their cleaning effectiveness, not just because they look "dirty."*** Also, leaving solvents open to the air creates unnecessary VOC emissions, and the money spent on the solvent evaporates. A way to use solvent more efficiently is to flush solvent into a trap for reuse in swishing the pressure pot. Also, solvent pumps should be maintained and replaced, as needed, to prevent leakage.

Used solvent should be reused for product formulation or for a

When considering what type of finish to use, remember that using water-based finishes eliminates the need to use solvents in equipment cleaning.

Regardless of whether aqueous or solvent solutions are used to clean equipment, there are a few techniques that will minimize the volume of the waste. First, if lines are being cleaned, use air to blow residue back into the pots before final cleaning with water or solvent; this reduces the amount of coating material wasted and helps to minimize the amount of cleaning fluid used. Second, when using water or solvent to clean, use high velocities instead of large volumes; this cleans more efficiently so that less cleaning fluid is required. Third, spray cleaning solvent into a container, preferably below the fluid line, for reuse instead of spraying the cleaning solvent into the air; this "used" solvent can be used for rough cleaning or for product formulation.

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COATING PREPARATION

Proper coating material preparation is important for waste and cost minimization. Too much reduction may result in sagging, whereas too little can cause poor flow, orange peel, and other defects. These problems can, in turn, result in rejects and wasted or unusable material. Here are a few tips to enhance the formulation:

! Always add the reducer to the material (instead of the reverse), and add it slowly while stirring vigorously.

! Test for complete mixing by taking a few drops from the top of the container and a few from the bottom; put each on a separate piece of glass, and watch for differences in color or rate of flow down the glass; noticeable differences probably indicate that additional mixing is needed.

! Mix materials well before use; some need to be mixed while in use to ensure the uniformity of the finish.

! Cover tanks to prevent evaporative losses.

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Section III

Case Studies

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CASE STUDY NO. 1—Conversion to HVLP

Introduction

Tiz's Door Sales, Inc. (TDS), is located in Everett, Washington, and employs over 60 people. TDS manufactures wood products for both remodeling and new home construction. Its product line includes interior and exterior doors and frames, window and base moldings, and stained railings.

Process Prior to Pollution Prevention

The company was using conventional spray guns, which were about 20 percent efficient manual-spray lines. High-quality finishes were obtained by using conventional solvent-based coatings.

Current Process

TDS was very aggressive in its source reduction efforts. TDS installed automated flat line spray equipment, which provides maximum application efficiency and recycles overspray, thereby saving 220 gallons of lacquer per week.

Where possible, solvents and coatings have been switched from toluene-based solutions to less hazardous blends. Heat, instead of solvents, is used to thin coatings for application.

TDS has converted all manual-spray lines to high-volume/low-pressure (HVLP) spray guns, which provide a high transfer efficiency (TE) and result in less overspray. This not only reduces the amount of waste generated but also provides immediate dividends by reducing the amount of coating material needed to finish each piece. Less overspray also means lower maintenance of equipment and lower labor costs. TDS found that using HVLP even resulted in a faster production rate—that is, although the application rate is slower, the drying time was less.

Using dedicated pumps and lines for each type of coating was another simple change that resulted in a large reduction in the amount of solvent needed. This reduced the cleaning required between coats. When cleaning is required, operators block gun nozzles and blow air back through the guns and delivery systems to reduce waste material even further.

Savings

TDS has reduced the amount of its coatings use by one-half. In 1991, 18,000 gallons were saved. At $10/gallon, this was a savings of $180,000! In addition, the company experienced significant savings in labor costs from less time spent on cleanup, maintenance, and material handling. Also, waste disposal costs were reduced dramatically.

The improved working environment is cleaner and safer, which has led to lower absenteeism and injury.

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Taken from "Success Through Waste Reduction; Proven Techniques from Washington Businesses, Volume II," Washington State Department of Ecology.

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CASE STUDY NO. 2—Solvent Recycling

Introduction

The Boling Company, located in Mt. Olive, North Carolina, manufactures wood office furniture with four different style lines and seven different finishes.

Process Prior to Pollution Prevention

Until January 1983, the company was burning spent solvents from the wood finishing process for fuel.

Current Process

In considering ways to reclaim spent solvents, Boling found it difficult finding commercial recyclers in its region. In 1983, Boling installed a "Little Still" to recycle spent lacquer thinners from the plant's washoff operations.

Early in the operation of the still, Boling encountered a few problems because of improper washoff collection practices. Boling realized that, in addition to problems associated with the washoff collection practices, Boling realized that the composition of the seven-component washoff solvent blend changed with distillation. It could not be reused in the washoff operation. However, by mixing one part acetone with three parts reclaimed solvent, the reconstituted mixture could be used as a thinner in the spray coating operation.

The plant's washoff operation generates about 10 to 15 gallons of spent solvent per day. Forty to 60 gallons per week are reclaimed for the spray operation. The still is operated four times per week to avoid accumulation of spent solvents. It operates on a 7-hour distillation/1-hour cooldown cycle. The rest of the solvents and the still bottoms remain in the plastic liner. The plastic bag liner is removed about once a week and burned in the plant's wood-chip fueled boiler for heat recovery. The boiler provides steam to the drying ovens and the drying kilns. In the winter, the boiler provides space heat for the plant.

Savings

In 1983, the cost of the still was $4,825. It was estimated that (1) the labor cost was $0.02 per gallon of solvent recovered, (2) the power cost was $0.05/gallon, and (3) the cost of the plastic bag liner containing the still bottoms was $0.05. This resulted in a total still operation cost of $0.12 per gallon of solvent reclaimed. With the addition of acetone to the seven-component washoff solvent blend, the mixture is reconstituted as a thinner. This reuse reduces the amount of virgin-blend solvent purchased for the spray mix. In 1985, the cost of the virgin-blend solvents was $2.67/gallon. The cost of reclaiming the solvent and adding acetone was $1.00.

The net savings is about $100 per week. In addition, the cost of disposal is avoided. Another

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Boling plant pays $0.40 per gallon to dispose of the same spent solvent. ***The still paid for itself in about 1 year of operation.***

Taken from "Managing and Recycling Solvents in the Furniture Industry," Industrial Extension Service, School of Engineering, North Carolina State University. May 1986.

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CASE STUDY NO. 3—Wood Waste to Energy

Introduction

Stanley Furniture (previously known as Burlington Furniture) is a furniture manufacturing company located in Lexington, North Carolina.

Process Prior to Pollution Prevention

The furniture maker shipped spent solvents to a landfill in South Carolina.

Current Process

Stanley installed an in-house incinerator to burn its spent solvents for heat recovery. The incinerator has a lower chamber and an upper chamber. Plant wastes are segregated into four groups: solids, heavy liquids (such as stains and glazes), sludges, and solvents. The solids and sludges are burned in the lower chamber. Wastewater from the rag wash is treated, and the residue is mixed with sawdust, in addition to water wash curtain sludges, and is burned in the lower chamber. The solvents are burned in the upper chamber, which uses No. 2 fuel oil as its primary fuel. The upper chamber runs at a temperature of 1,800°F. The heat from the incinerator fires a boiler to make steam, which is used to wash and dry rags. During winter, excess heat is used to supplement the plant's space heat. The incinerator ash is considered nonhazardous and is sent to the county landfill.

Savings

The incinerator was installed at an initial cost of $1.5 million. The facility anticipates a 3-year payback period. The incinerator burned 4,000 gallons of spent solvent, which was part of the 1.5 million pounds of waste burned in the incinerator. In addition to saving money in-house, Stanley made additional income by charging other small local furniture companies $29.00 per drum of spent solvents for incineration. Because of the high energy content of spent wash-off solvents, measured in British thermal units (Btu), Stanley finds that it is easier and cheaper to send its wastes to be used as fuel than to have solvents recycled.

Taken from "Managing and Recycling Solvents in the Furniture Industry," Industrial Extension Service, School of Engineering, North Carolina State University. May 1986.

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CASE STUDY NO. 4—Switching to Water-Based Inks

Introduction

Kemp Furniture Industries is a furniture manufacturing facility located in Goldsboro, North Carolina.

Process Prior to Pollution Prevention

Kemp Furniture has a five-stage printer for printing wood grain on fiberboard and plywood pieces before assembly and final finishing. Solvent-based inks were used in the printing line. Spent solvent from equipment cleanup was sent to a recycling company to be distilled and sold back to Kemp.

Current Process

Kemp Furniture's printing division switched from using solvent-based inks to water-based inks. The only adjustments needed for changing to water-based inks were a higher drying oven temperature and minimal operator training. The water-based inks are nontoxic, and wastes from press cleanups may be flushed into the city sewer without treatment.

The printing operation still requires the use of solvent-based finishes before and after printing; also, to keep the wood from showing through, some solvent-based coatings are still required when putting on a white finish. Kemp has made housekeeping improvements in its use of solvent-based finishes, including keeping waste streams segregated and effectively using solvents in a countercurrent manner. Virgin solvent is first used to flush out the pump and lines of the application equipment. This "spent" solvent is then used as a thinner for the finishing material. The solvent reclaimed by the recycling company is used for cleaning the dirtier parts of the equipment, such as rollers and belts. When this reclaimed solvent is too dirty for reuse, it is sent back to the recycler.

When there is no viable alternative to solvent-based finishes, Kemp reduces the use of solvents, thereby reducing the amount of spent solvent generated, by using different spraying equipment.

Savings

Water-based inks cost about one-half of the price of solvent inks. Kemp estimates that the change to water-based inks has reduced the printing line's spent solvents stream by 30 to 40 percent.

Taken from "Managing and Recycling Solvents in the Furniture Industry," Industrial Extension Service, School of Engineering, North Carolina State University. May 1986.

CASE STUDY NO. 5—Conversion to HVLP

Introduction

Thomson Crown Wood Products, Inc. (Thomson Crown), manufactures wood and wood-finished television cabinets in Mocksville, North Carolina.

Process Prior to Pollution Prevention

Thomson Crown sprayed its cabinets by using an air-assisted airless spray gun. These guns used air pressure of up to 55 pounds per square inch (psi) to atomize the coating material. This high pressure resulted in poor TEs.

Current Process

Thomson Crown tested four different HVLP spray guns using penetrating stain (no-wipe), glaze, sap stain, equalizer, toner, shade, and water-based black paint. Because of its specific product line, Thomson Crown chose a spray gun that would work well with a heavier finish. Each manufacturer produces a spray gun with slightly different properties—underlining the necessity of customizing equipment choice to product goals.

Using the HVLP spray guns, Thomson Crown has experienced the following reductions in material: (1) 65 percent for equalizer, (2) 65 percent for stain, (3) 65 percent for toner, (4) 35 percent for glaze, (5) 35 percent for no-wipe, and (6) 53 percent for water-based black paints.

In addition to using different spray guns, Thomson Crown has also altered its printing process room to incorporate roll-on finishings of all top and end panels of the outside cabinet. This modification resulted in 60 percent of the company's spray operations being diverted to the printing room. This reduced purchases of coatings by an additional 50 percent.

Savings

The material use reductions resulting from the change to HVLP guns total over 13,300 gallons per year of coatings, translating to an annual savings of over $137,000. The pollution prevention project cost of about $21,000 was recovered in 2 months.

Taken from "Pollution Prevention Case Studies," North Carolina Department of Environment, Health, and Natural Resources, Office of Waste Reduction. September 1993.

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CASE STUDY NO. 6—Reusing Overspray

Introduction

Medallion Kitchens, located in Waconia, Minnesota, is a leading woodworking company that manufactures kitchen cabinets and bathroom vanities. Medallion Kitchens was interested in using materials more efficiently to (1) reduce raw material costs, (2) reduce VOC emissions, (3) minimize hazardous waste disposal costs and the liabilities associated with hazardous waste disposal, and (4) decrease labor costs related to sludge removal, dewatering, and handling.

Process Prior to Pollution Prevention

Wooden cabinet pieces are stained and then finished with a solvent-based catalyzed sealer and topcoat before the pieces are assembled into the complete cabinets. Sealer and topcoat applications are automated. A central conveyor belt, two water-wash spray booths, and two drying ovens are all automated. Sensor-triggered automated spray guns apply coatings to cabinet parts in each spray booth. Overspray waste has been a problem. Before any changes were made, about 75 gallons of sealer were used per day, and the process generated about 50 gallons of hazardous waste sludge per day.

Process Changes

Medallion Kitchens decided to invest in a reclamation system to collect sealer overspray. The system consists of two holding reservoirs and minor plumbing. It was designed to catch most of the overspray before it fell into the water-wash tank.

Innovative features of the final reclamation system include the following:

- Cooling water was added under the collection trays to minimize solvent evaporation.
- Collected material is agitated to prevent "skinning."
- The reclamation tray and support assembly were designed to fit well into the spray booths and provide for easy removal.
- A nonstick coating was applied to the collection trays to decrease labor and material costs required for cleaning.

Collected solvents are recirculated through a pumping system to prevent curing. After about 5 gallons of overspray have accumulated, the overspray is manually removed and transferred to the mixing area. Solvent and catalyst are added to the material, as needed, to obtain the desired coating properties, and material is added back to the spray system to be reused. Some time is required for employees to maintain the new reclamation system. However, time is also saved, because the spray booth now requires less maintenance. The effective solids TE has increased from 40 percent before installation to about 80 percent. ***The system cost about $2,500 per booth to install, about $2,000 for materials,***

and about $500 for labor.

Savings

An average of 11.5 gallons of overspray was collected each day during October and November 1992. ***Assuming a raw material cost of $8 per gallon, Medallion Kitchens will save about $23,000 annually on raw materials as a direct result of collecting its overspray.***

Also, hazardous sludge generated by operations in the sealer spray booth has decreased from 50 to 25 gallons per day. ***Related waste disposal costs have been halved, saving the company around $30,000 per year, resulting in a total annual savings of $53,000.***

Taken from "Case Study: Reuse of Wood Finishing Overspray," Minnesota Technical Assistance Program. 1993.

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APPENDIX
ADDITIONAL INFORMATION

The following are additional documents on pollution prevention that you may find useful. Unfortunately, they are available only in English. Copies of documents with an U.S. Environmental Protection Agency document number may be obtained from the EPA Center for Environmental Research Information (CERI) or the Pollution Prevention Information Clearinghouse (PPIC). Some documents are available, without charge, from PPIC. For a current list of these documents, please contact PPIC.

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SURVEY:

DID YOU FIND THIS MANUAL USEFUL?

Please help us by answering the following questions:

A. PROFILE OF YOUR ORGANIZATION

( ) Trade Association ( ) Business ( ) Government Office

( ) Other ______________________

What product or service does your business/organization provide? ______________________

____

How old is your business/organization? __ years

How many employees work in your business/organization? __

B. TRAINING NEEDS

U.S. EPA and SEDESOL plan to add sections to this manual or develop new manuals for other industries in the border area. Which industries should be addressed next? ______________________

( ) Agriculture Chemicals ( ) Other ______________

What type of training would you attend?

( ) Technical Workshops ( ) General Training ( ) None ( ) Other ______________

U.S. EPA and SEDESOL are considering holding training sessions on "pollution prevention."

What information would be useful to you in this area?

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C. USEFULNESS OF MANUAL

Did you find the format of this manual useful? ( ) Yes
( ) No

Did you find its content useful? ( ) Yes
( ) No

How would you improve it? ____
____

What other information should be included? ________________________________
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Who else should receive this manual?

Name: ____________________ ____________________

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D. ADDITIONAL COMMENTS

Please provide any additional comments on this manual and its usefulness.

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Please fold on the dotted line and mail. If you have any questions regarding this publication or would like additional information, you may contact ***U.S. EPA (214) 665-6580***, or ***SEDESOL (525) 553-6421***.

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ROBERT LAWRENCE (6M-PP)
POLLUTION PREVENTION COORDINATOR
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DALLAS TX 75202

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